

# LOOPBACK RADIO FREQUENCY TRANSLATOR FOR THE ACTS MOBILE TERMINAL

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## ABSTRACT

The ACTS Mobile Terminal (AMT) is a ground based mobile satellite communications terminal designed to operate with the NASA Advanced Communications Technology Satellite (ACTS). With a scheduled launch in mid-1993, propagation experiments will begin in late 1993. This will be done to characterize the communications path between a fixed communication site in Cleveland, Ohio and a mobile terminal in Southern California via ACTS. The terminal uplink frequency is  $29.634 \text{ GHz} \pm 150 \text{ MHz}$  and the downlink frequency is  $19.914 \text{ GHz} \pm 150 \text{ MHz}$ . A pilot signal at  $29.630 \text{ GHz}$  will be transmitted from the fixed site for antenna tracking by the mobile terminal. This paper summarizes the system design and performance measurements of the Loopback Translator, a satellite simulator to be used in testing the fixed and mobile terminal hardware prior to the ACTS launch. The Translator provides full duplex, single stage up and down conversion between the  $3.373 \text{ GHz}$  Intermediate Frequency (IF) and the transmit/receive frequencies.

## 1. INTRODUCTION

The National Aeronautics and Space Administration (NASA) has developed, through the Lewis Research Center, the Advanced Communication Technology Satellite (ACTS) as shown in Figure 1. ACTS, presently scheduled for launch in mid-1993, is an experimental communications satellite with transmit and receive frequencies of  $20 \text{ GHz}$  (K-Band) and  $30 \text{ GHz}$  (Ka-Band), respectively.

With the Jet Propulsion Laboratory's (JPL) expertise in mobile communications, the ACTS Mobile Terminal (AMT) is currently near completion and will work in concert with ACTS. Various tests and experiments will be done utilizing the AMT to verify the feasibility of mobile communications at Ka-

band. Once in orbit, ACTS will be used to test communication capabilities of the Ka-band hardware by transmitting voice and data from JPL in Pasadena, California to the Lewis Research Center in Cleveland, Ohio and vice-versa as shown in Figure 2.

To test the AMT hardware before the launch of ACTS, a simulation will be done entirely in and around JPL (Figure 3). This experimental setup depicts the Ka-band communications hardware stationed in a fixed location (on top of JPL bldg. 238) and in a van that moves within the confines of the lab. The center icon, an antenna mast or tower, represents the JPL antenna range. The Radio Frequency (RF) Translator, which is an ACTS simulator, will sit on top of the mast and be used to check the capabilities of the AMT hardware by relaying voice and data information between the mobile and fixed terminals (Figure 4(a) and (b)).

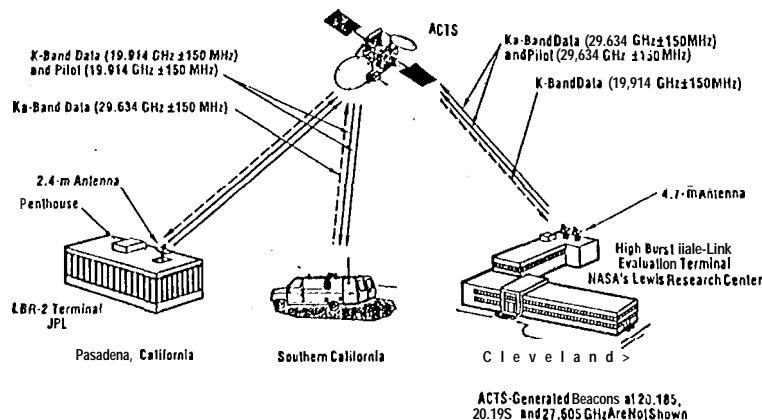


Figure 2. ACTS system set-up between JPL and NASA Lewis.

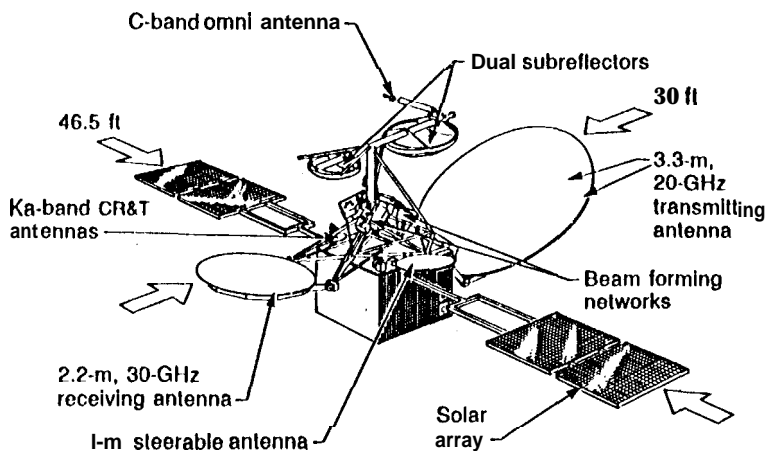


Figure 1. ACTS spacecraft configuration.

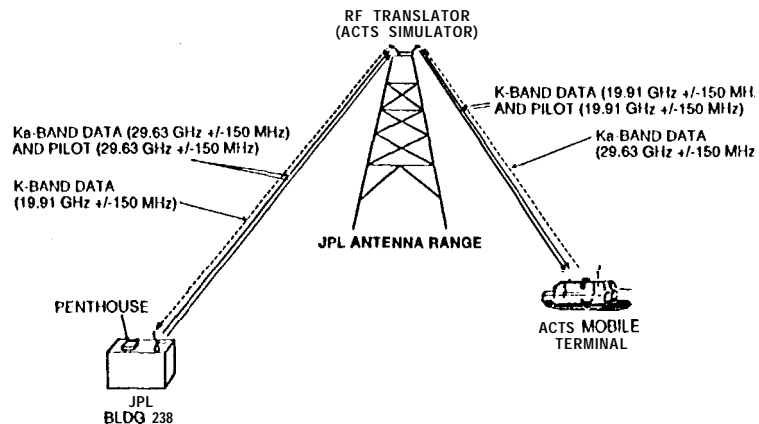


Figure 3. Test of AMT hardware in and around JPL will involve the RF Translator.

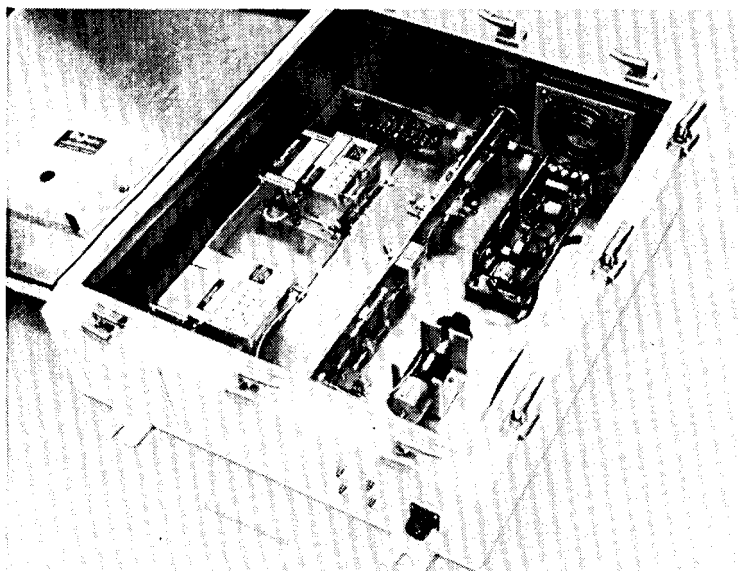
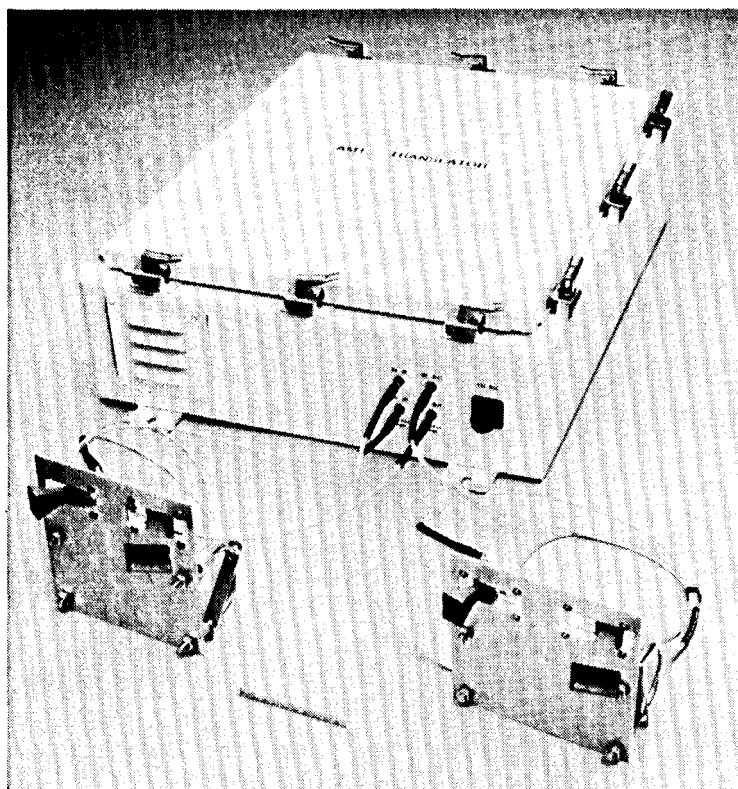


Figure 4. Radio Frequency Translator. (a) Enclosure (top) with transmit and receive antennas attached (b) Interior view (bottom) showing layout of RF electronics.

The RF Translator is a ground transponder which can receive a Ka-band uplink signal of  $29.634 \text{ GHz} \pm 150 \text{ MHz}$  and convert it directly to a K-band transmit signal of  $19.914 \text{ GHz} \pm 150 \text{ MHz}$ . This Ka-band signal (voice or data) with an unmodulated pilot tone of  $29.630 \text{ GHz}$  will be received in the forward direction from the fixed terminal. The unmodulated pilot is used by the mobile terminal for antenna tracking, as a frequency reference for Doppler correction and pre-compensation, and for measuring rain attenuation. For system efficiency, the pilot is transmitted only in the forward direction, i.e., from fixed to the mobile terminal. This signal and pilot are translated to  $19.914$  and  $19.910 \text{ GHz}$ , respectively,

and transmitted to the mobile terminal. In the return direction, from the van to fixed site, a single modulated signal is transmitted and converted to a K-band signal. The performance and link specifications for the Translator were determined by the system engineer of the AMT project.

In designing this satellite 'simulator, the goal was to use existing components from the RF subsystems of the AMT and any off-the-shelf components to minimize development cost. Since the Translator will be outside on the antenna mast, it was imperative to shield the microwave components from the environment. A weather-proof enclosure was integrated into the system design.

## II. TRANSLATOR SYSTEM DESIGN

The design requirements for the Translator are summarized in Table I. From these parameters, the system design was done using two design tools. The first was a custom spreadsheet which used component gain and noise figure data to calculate the system noise temperature and power levels at every component in the system. The second tool used was OMNISYS, a commercially available system analysis software package that used spur analysis data taken from the up- and down-conversion mixers to aid in the design of filters used within the receiver and transmitter. Other aspects of the system design involved the breadboarding phase, an antenna mounting design and thermal analysis.

TABLE 1.  
RF TRANSLATOR REQUIREMENTS

### Receiver:

Uplink frequency=  $29.634 \text{ GHz} \pm 150 \text{ MHz}$   
 $G/T = -23.94 \text{ dB/K}$   
 $C/No = 88.05 \text{ min}$   
 $119.95 \text{ rmax}$

Receive Antenna Beamwidth =  $\pm 15$  degrees  
 Receive Antenna Polarization = horizontal

### Transmitter:

Downlink frequency=  $19.914 \text{ GHz} \pm 150 \text{ MHz}$   
 $EIRP = -84.51 \text{ dBW min}$   
 $-52.61 \text{ dBW max}$

Transmit Antenna Beamwidth =  $\pm 15$  degrees  
 Transmit Antenna Polarization = vertical

### Physical Requirements:

Power Supply =  $115 \text{ VAC}$   
 Temperature Range =  $0$  to  $50$  degrees Celcius  
 Weatherproof Enclosure

### A. Design Control Tables

These spreadsheets are organized based on two transmit and receive scenarios as shown in Figure 5. In scenarios 1 and 2, the uplink signal is transmitted from the fixed terminal to the Translator and then to the mobile terminal. The return signal is sent from the mobile terminal to the fixed terminal via the Translator. Note the distance from the fixed terminal to the Translator is  $600 \text{ meters (m)}$  and  $15 \text{ meters}$  from the Translator to the mobile terminal. These distances have a direct bearing

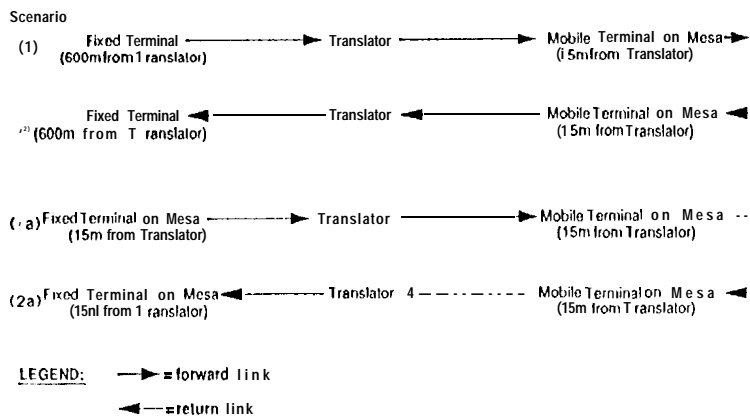


Figure 5. AMT experimental transmit and receive scenarios.

on the power levels received and transmitted by the simulator due to the space loss along the path. In scenarios 1a and 2a, both the fixed terminal and mobile terminal are located on the JPL antenna range close (-15m) to the Translator. Thus the power levels need not be as great due to a decrease in space loss,

## B. OMNISYS Analysis

The second tool, C) NISYS, was used to confirm the spreadsheet analysis and perform the system spur analysis. The system is analyzed by entering a netlist containing component descriptions and analysis information. Within the software, an intermodulation table is utilized, incorporating specifications obtained from the manufacturers data sheets or data through direct measurement of the target mixers. This table is a spreadsheet of expected spur levels at one operating point defined by the input signal level/frequency and the local oscillator (1,0) signal level/frequency.

The equations defining the spurious frequencies for the Translator and used by the software are [2]:

$$\text{Downconversion: } F_{\text{nrn}} = N * \text{FRF} + M * \text{FLO}$$

where  $F_{\text{nrn}}$  = frequency of the ninth spur  
 $\text{FRF}$  = Downconvert RF frequency  
 $\text{FLO}$  = Local Oscillator frequency

$$\text{Upconversion: } F_{\text{nrn}} = N * \text{FIF} + M * \text{FLO}$$

where  $F_{\text{nrn}}$  = frequency of the ninth spur  
 $\text{FIF}$  = Upconvert IF frequency  
 $\text{FLO}$  = Local Oscillator Frequency

A simulation of the up and down conversion system was obtained which gave the unfiltered performance. These results were analyzed to determine the proper filter specifications in terms of bandwidth and stopband attenuation to achieve the spurious frequency level requirement of -50 dBc.

Downconverter spurious frequency analysis indicated that the LO "leakage" was the largest spur requiring 62 dB of attenuation. With a desired bandwidth of 300 MHz for the IF of 3.373 GHz, the harmonics generated by this mixing process were allowed to propagate out of the IF port of the mixer. An existing tubular S-band filter, available from another subsystem of the AMT equipment, was used on the IF port of the mixer to attenuate the generated spurs. The filter provided over 60 dB of rejection at the LO frequency of 13.1305 GHz due

to the large frequency separation from the IF. insertion loss was less than 1.6 dB.

The Upconverter spurious frequency analysis was conducted in a similar way using an upconvert mixer intermodulation table. The spur analysis continued at the output of the upconversion mixer because RF spurs were found to be prevalent at the output. The largest spur, again, was from the LO "leakage" at 16.541 GHz. With an output RF frequency of 19.914 GHz  $\pm$  150 MHz, a K-band bandpass filter was designed and procured such that it provided 70 dB of rejection at 16.541 GHz and 60 dB of rejection at 22.5 GHz to meet the -50 dBc spurious frequency level requirement. Insertion loss at the center frequency was less than 1 dB.

## C. Breadboard

This is the proof-of-concept phase of the Translator development. Figure 6 shows the block diagram used to verify the operational capability of the Translator. A majority of the components used in the breadboard were spares from another phase of the AMT hardware development that would be identical to those used in the Translator. The design control table parameters were used to set the power levels for the receiver and the predicted power levels were checked on the output of the transmitter. The results of these tests confirmed the frequency conversion from 29.634 GHz to 19.914 GHz and power translation. It should be pointed out that the portion of the block diagram assembled was from the 29 GHz Low Noise Amplifier to the K-band bandpass filter. The antennas, waveguide-to-coax transitions, and the power combiners/dividers were not available.

The analysis indicated that spurs were being generated by the 16.541 GHz local oscillator used in the upconversion process. To reduce the effect these unwanted signals might have on the mixing process, it was determined that a filter was needed at the output of this oscillator. An existing bandpass filter, designed for a similar filtering application for the AMT hardware, was used at the output of the local oscillator. This filter provided more than 30 dB of rejection within the 3 dB passband of 15,461-17,805 GHz. The insertion loss provided by this device is less than 1 dB in the passband.

## D. Antenna Mounting

The Translator, when mounted on the antenna mast, will use aperture antennas for the receiving and transmitting frequencies previously specified (Figure 4(a)). These horns, to be pointed at sites on the lab where receiving and transmitting equipment will be located, required a mounting scheme that allowed two degrees of freedom (vertical and horizontal) for 'manual pointing. The mounting plates and slides were designed and fabricated at JPL to accomplish those needs. Two inch U-bolts were used to attach the assembly to the mast support structure.

## E. Thermal Analysis

The active components of the Translator are the amplifiers, oscillators and the power supply. Exposing this system to the environment would require placing the components in a weather-proof enclosure for protection. However, the heat generated may have an effect on the overall system performance. Therefore, a thermal analysis was performed by the Applied Mechanics group at JPL to determine the cooling needs for the system and to evaluate a weatherproof enclosure. The parameters given for the analysis were 72 Watts of internal

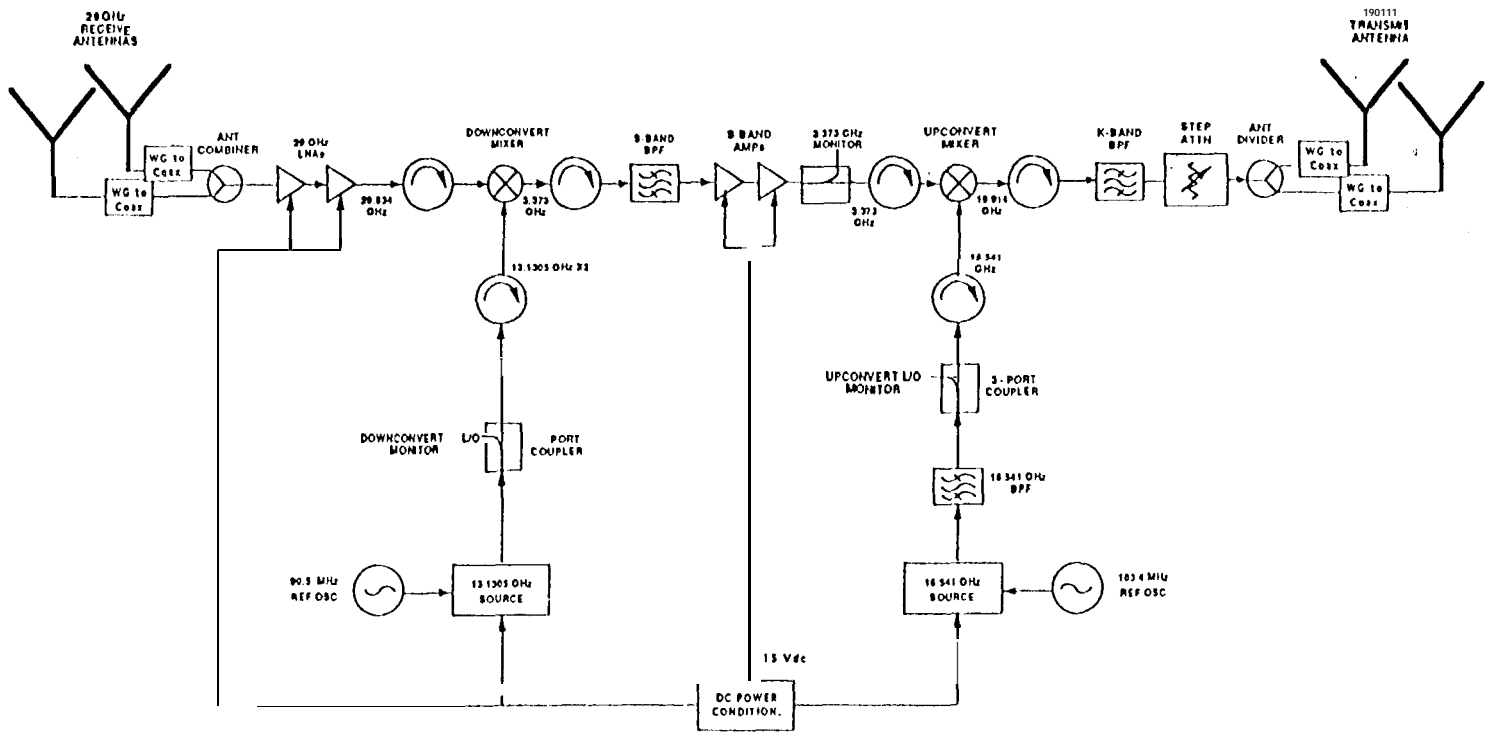


Figure 6. Translator functional block diagram.

heating by the components (worst case), enclosure dimensions of 61.00 x 51.00 x 15.00 centimeters (cm) with an internal mounting plate and a maximum internal temperature of 40 degrees Celsius. Based on this analysis, painting the box white with a paint that has high emissivity and low absorptivity and installing a fan of at least 1.44 cfm were adhered to in the system design,

## 111. TEST

Testing of the Loopback Translator involved component and system level tests and the results were compared to the predicted values and design control table data.

### A. Component Tests

Each component or subsystem of the Translator was tested. Two port devices such as amplifiers, isolators, filters, etc. were checked using the HP8510C Vector Network Analyzer and the measured S-parameters were verified with the manufacturer specifications. A Tektronix 2782 Spectrum Analyzer was used to measure the performance of the oscillators and mixers. This analyzer is especially useful for mixer measurements because it allows direct measurement in coax to 33 GHz without an external mixer. An HP8341A frequency synthesizer was used as a frequency source for these measurements. Spectral measurements of these components were obtained for a spur analysis (section 11) of the up- and down- conversion schemes employing the mixers and oscillators.

### B. System Tests

Comprehensive testing of the entire Translator to verify system performance was completed. The measurement setup block diagram, shown in Figure 7, was used for most of the system level tests. The frequency synthesizer was set to 3.373 GHz with -18 dBm output power to drive the frequency converter. The frequency converter translated the signal to 29,634 GHz with 0 dBm  $\pm$  15 dB output power. The input

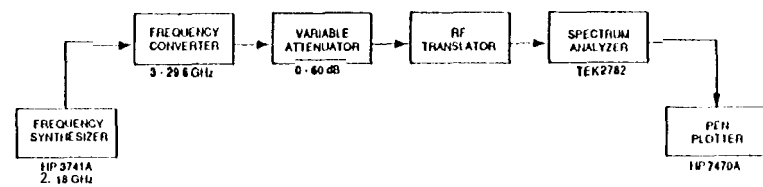


Figure 7. RF Translator measurement block diagram.

power level to the RF Translator under test was adjusted by the manual variable attenuator to levels indicated in the design control tables. The output spectrum was measured on the Tektronix 2782 spectrum analyzer which was interconnected to the translator by coax (low loss flexible cable with K-connectors). Hard copies of the measured spectra were made with the pen plotter.

The first test performed dealt with verifying the output frequency and power level for a given input frequency and power level. The different power levels were found in the design control tables mentioned earlier in section II. Upon examining the output spectrum on the spectrum analyzer, it was noticed that a constant signal, 20 dB lower than the center frequency, appeared on both sides of the carrier and was 182 kHz away from the center frequency. It was determined this was noise from the AC-DC switching power supply that was infiltrating the transmit signal. To alleviate this problem, a lowpass filter scheme using an inductor (a toroid with 20 turns) was placed on the power supply 15V output line.

Frequency, power translation, and gain translation performance for the four scenarios previously mentioned were verified. A swept measurement to determine the gain flatness of the Translator passband (19.914 GHz  $\pm$  150 MHz) was made and the results achieved ( $\pm$  0.8 dB) were better than the  $\pm$  1 dB specification. The entire 300 MHz band was scanned by

adjusting the spectrum analyzer to narrow windows of 1 MHz to detect any spurious frequencies out of specification. All spurious frequencies were found to meet the required level of -50 dBc.

Although no specific requirements were given for gain compression and return loss, these parameters were measured to insure completeness. The gain compression curve obtained for the Translator indicated that a 7 dB gain margin is available above the maximum expected signal level. Input return loss at 29.6 GHz was -19 dB and output return loss was found to be -27.8 dB.

Finally, during actual operation of the satellite simulator, multiple signals are expected to be received and transmitted by the Translator. The fixed terminal transmits both a modulated carrier and an unmodulated pilot tone. As both of these signals will be present in the Translator simultaneously, two tone measurements were performed to confirm the performance. This included the examination of intermodulation characteristics in the presence of two signals at various offsets. It was determined that with a fixed pilot signal as specified by the AMT project, a narrow 3 MHz window exists where no intermodulation products fall in the band. This window occurs when the modulated signal frequency is in the upper 3 MHz of the passband.

#### IV. CONCLUSION

The design, development, and test of an ACTS Satellite simulator for the Jet Propulsion Laboratory has been completed. The design process involved using state-of-the-art microwave system analysis tools and techniques. Advanced microwave and millimeter-wave measurement equipment was also employed to confirm component performance. Finally, overall system performance was verified and documented.

The Translator is a key component in the test and evaluation of the ACTS Mobile Terminal prior to actual operation with the satellite. With this piece of test equipment, satellite communication functions can be fully tested and verified.

Operation of the terminal can be determined in the event the satellite launch is delayed. Finally, complete operation can be verified at JPL prior to shipment of the fixed terminal to the NASA Lewis Research Center saving costly travel and support for preliminary testing.

#### ACKNOWLEDGMENTS

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This paper is a summarized version of the report [1] that characterized my senior design project (ASU course EEE 498) at JPL. The tasks involved in each phase of the Translator's development were the responsibility of myself with my advisor, Rick Crist, giving direction as needed.

It is a pleasure to acknowledge my advisor, Rick Crist of JPL's section 336, the Spacecraft Telecommunications Equipment section, for his guidance, support and abundant encouragement. Also, thanks goes to Dr. Dan Rascoe, my immediate supervisor, who made it possible for a co-op position to be available in his group. The experience gained and direction received as to my career interests were positively impacted during my seven month co-op tour. Thanks must also be extended to Dr. James Aberle, advisor of the ASU IEEE Student Chapter and Dr. Gay Brack of the ASU English Department for their encouragement, support and assistance in the reorganization and writing of this paper.

#### REFERENCE LIST

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